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Final Report: Design and Optimization of Passive and Active Imaging Radar

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June 3, 2002

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1 Objectives

Our effort focused on the development algorithms for tracking, imaging, and recognizing aircraft via radar systems by exploiting statistical inference techniques, state-of-the-art physics-based modeling of electromagnetic phenomena, and advances in digital signal processing. Although this thrust considered both passive and active radar, the prime motivation of our study was the fascinating new class of passive (also called "parasitic" or "hitchhiking") radar systems which exploit "illuminators of opportunity" such as commercial television, FM radio, or cell phone broadcasts. Such systems may remain entirely covert, unlike traditional active radars which reveal their presence and location through their transmissions. These sorts systems have gained notably increasing attention over the years that we have been investigating them; for instance, Roke Manor in the U.K. is currently developing such a system based on cell phone transmissions, and the French have been experimenting with systems exploiting digital broadcasts. The clandestine nature of such systems and their alleged potential for detecting low-observable targets has also brought them much attention from the mainstream press.

The cost dynamics of passive radar systems are also attractive. A large portion of the cost of a traditional active radar systems is in the transmitter, whereas designers of "hitchhiking" or "parasitic" radars have high-power, wide-coverage transmitters already available. The tradeoff lies in the realization that most communication systems are narrowband and are not designed with radar applications in mind; however, this is potentially mitigated by the sheer number of exploitable transmitters that are out there. The cost then shifts from the active radar's transmitter to the development of algorithms capable of making sense of the measured "ethereal babble" – the tangled weave of signals arising from both sources in the environment and reflections off aircraft of interest – and the

development of hardware to execute those algorithms. The cost of an active transmitter remains relatively fixed, while cost of computational horsepower continues to decrease.

We anticipate our research contributing to passive radar systems as illustrated in Figure 1. The items labeled in blue indicate aspects of the many currently implemented systems, namely the tracking of targets using positions and velocities. Of immediate interest is using the position and velocity information, augmented with the magnitude and phase of the returned signals, to both image and classify targets. The classifier we have implemented compares the received signals to signals predicted using the Fast Illinois Solver Code (FISC) developed at the Center for Computational Electromagnetics at the University of Illinois. The system may encounter targets which are not in the classifier's library; hence it will be helpful to form images of such targets to give to a human analyst. Alternative target classifiers that use the result of an imaging stage as input could also be explored in the future. These classification and imaging efforts are indicated using black lettering.

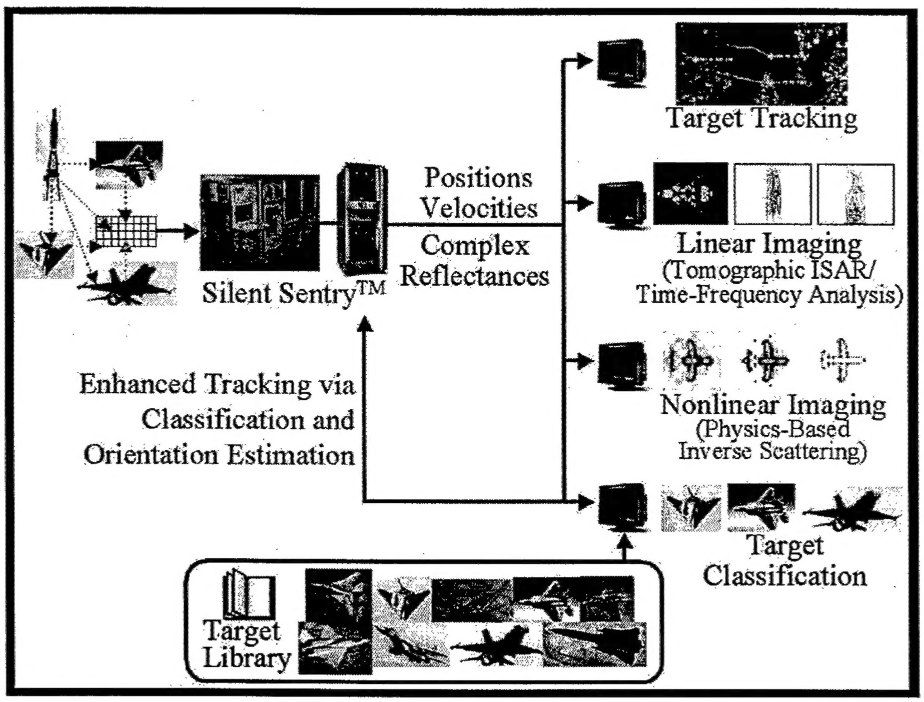

Figure 1: Anticipated eventual contributions to Lockheed Martin's Silent Sentry™ and similar systems.

The red lettering indicates the more ambitious goal of introducing feedback between the recognition and tracking stages. Another component of our project resided in the theoretical domain of nonlinear inverse scattering. Most of this work has been in two dimensions, which provides a testing ground for the more analytically and computationally complex three-dimensional electromagnetic problem. Although some of our results in this area may not be currently implementable in a real-time system, they provided

theoretical underpinnings for other aspects of the project. In addition, the continued increase of computing power (along with decreasing costs) may eventually make the more computationally intensive algorithms more practical for real-time implementation.

1.1 Related Work

In the United Kingdom in the mid-80s, Griffiths and Long [1] attempted to extract range information from backscattered television signals. Plagued by the low signal-to-noise ratio resulting from the available equipment and the range ambiguity inherent in the sync pulses of an analog TV signal, the results did not seem encouraging. However, a decade later, Howland [2] successfully tracked targets by abandoning any attempt to directly measure range in favor of the velocity information contained in the doppler-shifted TV carrier and the angle-of-arrival information derived from a simple two-antenna array. Exotic track initialization algorithms, combined with a Kalman filter, fuse the doppler and angle-of-arrival information into Cartesian coordinate tracks. The most sophisticated manifestation of this kind of technology is probably the Silent Sentry system developed by Lockheed Martin Mission Systems of Gaithersburg, MD, which can exploit both analog television and FM radio signals. We have been fortunate to be able to collaborate with Lockheed Martin's Passive Coherent Location (PCL) group who have been advising us over the course of this research (as an unfunded and unfunding partner) and provided real data collected with their Silent Sentry testbed. Another well known system is the Manastash Ridge Radar developed by the University of Washington [3, 4], which uses FM radio-based passive radar for atmospheric studies. Other testbed systems are under development by Dynetics [5].

A number of Italian researchers [6, 7] have considered passive radar for imaging large areas of terrain. To achieve the necessary resolution and signal-to-noise ratio, they consider integration times on the order of half a day. With such large integration times, moving objects (such as tree leaves blown by the wind, ocean surfaces, etc.) tend to be canceled out in such terrain mapping systems. In particular, Prati [6] *et al.* investigate the feasibility of a parasitic SAR system exploiting digital audio broadcasts (operating in the L-band, with a carrier frequency around 1.5 GHz and a bandwidth of 4 MHz). Cazzani *et al.* [7] report experimental results obtained from a ground-based receiver exploiting digital TV broadcast satellite transmissions (with a bandwidth of approximately 20 MHz).

2 Accomplishments and New Findings

A selected set of papers documenting accomplishments and new findings are provided in the appendix. The paper compilation in the appendix is meant to be representative of the overall scope of the work and is not intended to be exhaustive. Complete references are given in the Publications section. Most of the papers listed may be downloaded from users.ece.gatech.edu/~lanterma/pcl.

2.1 Making FISC Compatible Models with GeomFix

The ability to simulate the electromagnetic scattering of aircraft-sized targets is important to our study in two aspects: first, it allows us to build target libraries for automatic target recognition (ATR) algorithms; and secondly, it allows us to test those ATR algorithms as well as test image formation algorithms.

We have consistently employed the method-of-moments code FISC, developed by the Center for Computational Electromagnetics at the Univ. of Illinois (and distributed by SAIC Champaign as part of the XPATCH package), throughout our project. Unfortunately, FISC is quite picky about the quality of models which it takes as input. In particular, the model must be a single closed surface, and every edge of every triangle must line up exactly with some edge of some other triangle. Such models are rare. In our previous work, we either built such models from scratch (scanning in diagrams and typing in coordinates) or were luckily enough to find a model which could be readily made FISC compatible. These models include the VFY-218 (which came with FISC), the Flying Bat (built from scratch from hobby shop sources), the Falcon 20 and 100, the F-22, and the T-38A (all purchased from Viewpoint, a 3-D content provider whose primary customer seems to be the entertainment industry) and the Cessna 402c (free demo model from Viewpoint).

To facilitate expansion of our model library, we purchased the GeomFix software made by MATIS, Inc. GeomFix contains many tools for taking a "messy" CAD model and making it FISC compatible. However, the process is far from fully automated, and effectively wielding the power of GeomFix seems to be far more of an art than it is a science. We have been in frequent contact with MATIS, reporting bugs and making suggestions for improving the GeomFix package. Fig. 2 shows FISC-compatible models of an X-29 and F-15 made with GeomFix. The source for the X-29 model was a facet file provided with the standard XPATCH distribution. The F-15 model was purchased from Viewpoint. Both models required substantial and tedious cleanup with GeomFix.

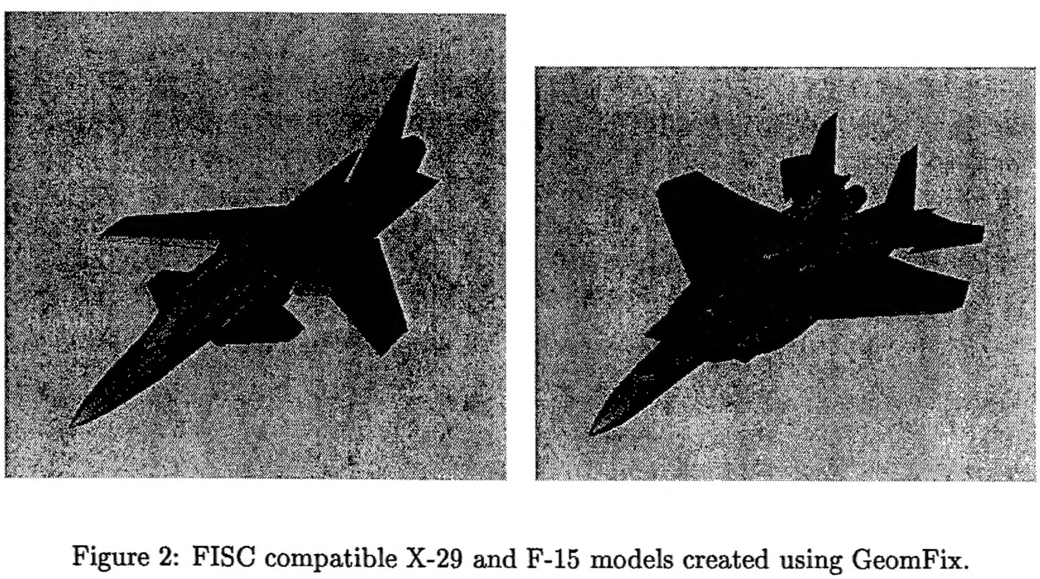

Figure 2: FISC compatible X-29 and F-15 models created using GeomFix.

		Recognized Class				
		Falcon-20	*Falcon-100*	*VFY-218*	*Flying Bat*	*F-22*
Correct Class	*Falcon-20*	931	68	0	0	1
	Falcon-100	80	834	24	10	52
	VFY-218	1	14	965	13	7
	Flying Bat	0	21	3	872	104
	F-22	0	80	10	131	779

Table 1: Recognition performance of stand-alone classifier on a five-class problem. Noisy observations of RCS were synthesized from the GPS ground truth, but Lockheed Martin's actual state estimates were used to compute likelihoods.

We hope that the availability of more FISC compatible models will increase interest in FISC and other method of moments codes, such as those developed under DARPA's Virtual Electromagnetic test range. It should be noted that our models have *not* been rigorously validated against real test data, nor do we plan to, as doing so might lead to difficulties with security classification. The models are intended solely to provide proof-of-concept support in the development of imaging and recognition algorithms.

2.2 Tracking and Classification

Classification via Target Libraries: Lockheed Martin Mission Systems supplied us with actual radar data (delay, Doppler, and received power) collected during a field trial conducted in 1999. The purpose of the trial was to demonstrate the tracking capabilities of their system against a Dassault Falcon 20 (a small commercial jet) as it executed various maneuvers. Lockheed Martin also supplied us with their radar system's position and velocity estimate for the trajectory of the Falcon-20, as well as the GPS ground truth from the trial.

With this data, we were able to conduct two types of experiments. The first type consisted of simulations in which we synthesized noisy observations of RCS using the GPS ground truth and the known locations of the receiver and FM illuminators. By synthesizing RCS data in this way, we were able to vary the identity of the correct target class. However, we still used Lockheed Martin's state estimates. Thus, the observed RCS was mismatched to the position data (to whatever extent the state estimates happened to be in error). Using this approach, we conducted a five-class recognition experiment. We performed 1000 Monte Carlo simulations for each choice of correct class (i.e., 1000 runs where the Falcon-20 was the true target, 1000 runs where the VFY-218 was the true target, etc.). The track consisted of 428 samples and the observation likelihood was assumed to be Ricean (reflecting the assumption of independent additive Gaussian noise in each branch of Lockheed Martin's quadrature demodulator). The resulting confusion matrix is shown in Table 1. For all five target classes, there is enough information in the observed RCS to correctly classify the unknown target at least 77% of the time.

The second type of experiment we performed was actual classification using the measured power provided by the Silent Sentry system. Because the data we received from

Lockheed Martin is protected under a non-disclosure agreement, we do not show plots that compare our estimated RCS to the measured RCS here. Instead, we show RCS curves based on GPS ground truth for a single illuminator and a portion of the complete trajectory. Fig. 3 displays the expected RCS as computed using our FISC databases for three of the five target classes. This figure is meant to demonstrate, using an actual aircraft flight path, that there are substantial differences between the RCS curves of competing classes. This would be expected to lead to robust classification performance. In fact, we were able to correctly classify the Falcon-20 using the actual received power measurements from the Lockheed Martin trial out of the same set of models used in our Monte Carlo study. Careful consideration of various details of the Silent Sentry system (such as the array antenna pattern) was essential in order to wrangle the raw Silent Sentry data into a form amenable to our RCS classifier. Lockheed Martin Mission Systems[1] was quite helpful in providing these important details.

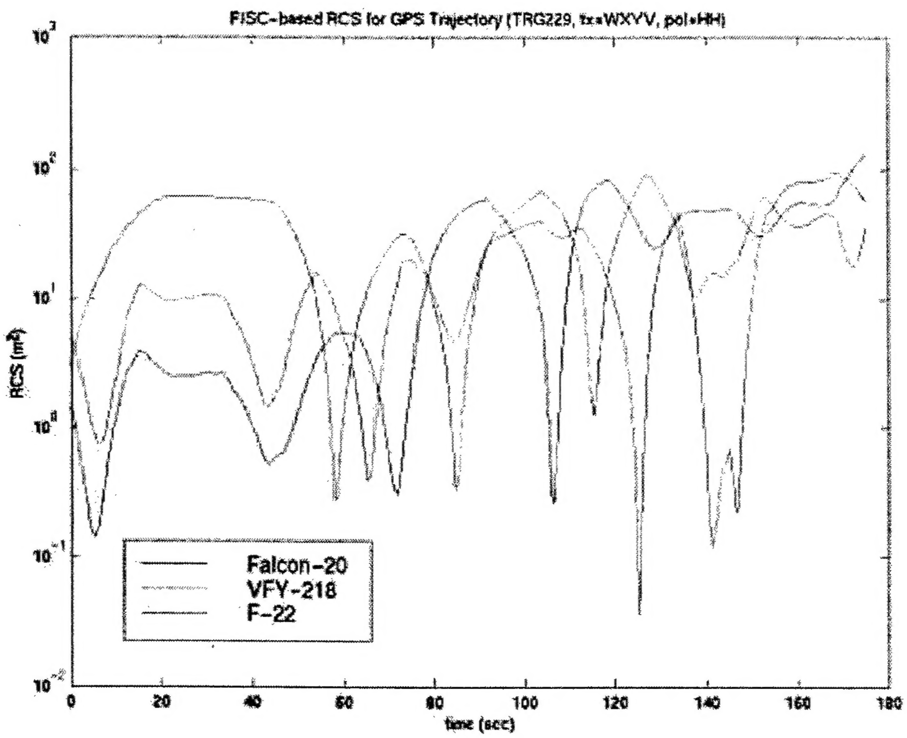

Figure 3: RCS curves for three of the different target classes computed using FISC and the GPS ground truth.

Joint Tracking and Classification with Nonlinear Filters: We have fused RCS data with delay and doppler data in an attempt to get better classification and more accurate target tracks by linking position and orientation estimates though nonlinear

[1]We would like to thank Dr. Bert Bradford and his colleagues for their continuing technical assistance throughout this project, as well as Dick Lodwig for his sage advice and overall support.

dynamical equations of motion. Preliminary work on using particle filters [8, 9, 10] (also known as "condensation" or "sequential Monte Carlo" filters) to perform inference is documented in the appendix in "A Particle Filtering Approach to FM-Band Passive Radar Tracking and Automatic Target Recognition." Shawn Herman's doctoral dissertation on this work is expected to be completed in August 2002.

2.3 Radar Imaging

Imaging With Realistic Sampling Patterns: The conference paper "Deconvolution Techniques for Passive Radar Imaging" provided in the appendix shows results of imaging using the kinds of Fourier samplings which would arise from using a passive radar system with narrowband transmitters. It also shows results of applying the CLEAN algorithm [11, 12] to these images. The results illustrate the need to search for more sophisticated techniques. Yoram Bresler and his student Raman Venkataramani have developed a body of theorems characterizing the sparse imaging problem. References describing their work are listed in the Publications section. Copies are not given in the appendix since they are lengthy and highly mathematical; they are available for download from users.ece.gatech.edu/~lanterma/pcl. Some of their recent papers extend their theory to the multiple-input multiple-output case, which could be applied to polarimetric imaging.

Wide-Angle Imaging: We have crafted methods of imaging from wide-angle data using time-frequency transforms. These methods allow us to deal with target reflectivities with change with aspect angle. We have demonstrated that time-frequency transforms permit the elucidation of features which are either blurred or canceled out using traditional direct Fourier reconstruction. A journal paper draft giving theoretical analysis to explain the observed effects and numerical studies using FISC called "Wide-Angle Radar Imaging using Wigner-Ville Distributions" is given in the appendix.

Autofocus Algorithms: Our existing imaging algorithms have assumed that accurate phase information is available in the complex radar data. We are exploring ways to tie autofocusing techniques into our imaging algorithms.[2] Some preliminary work comparing relevant autofocus algorithms is reported in the appendix in "An Experimental Study of a New Entropy-Based SAR Autofocus Technique." Some recent experiments with simulated annealing are showing much promise.

Iterative Algorithms for Statistical Radar Imaging: We have developed a fast implementation of an iterative expectation-maximization algorithm for generating delay-doppler images with higher resolution than that obtainable with traditional matched filtering. The latest version of this ongoing work is described in the attached conference paper "Efficient Implementation of an Expectation-Maximization Algorithm for Imaging Diffuse Radar Targets." This work has a dual-use application in radio astronomy, which is documented in a book chapter available for download from users.ece.gatech.edu/~lanterma/pcl.

Holographic Reconstruction on a Digital Computer: We have derived an algorithm based on holographic backprojection principles to combine information from differ-

[2]It is unlikely that such algorithms will be usable on the Lockheed Martin data set we currently possess; the long integration time used by Silent Sentry implies that the target has moved many wavelengths over the time that a single data point is formed, rendering the phase information essentially random. Data sets collected with shorter integration times, so that the "stop and go" model typically used in radar imaging is valid, would be quite helpful.

ent polarizations; this work is archived in a paper submitted to IEEE Trans. on Antennas and Propagation. We have not attached the paper since it is lengthy and highly technical; instead, we will show some more recent results here.

We have reconstructed airplane projections from three-dimensional airplane models, using only data collected from line apertures, *taking the polarization of electromagnetic waves fully into account.* These linear algorithms are based on the holographic backpropagation principle and the vector Porter-Bojarski equation. Details are given in [13].

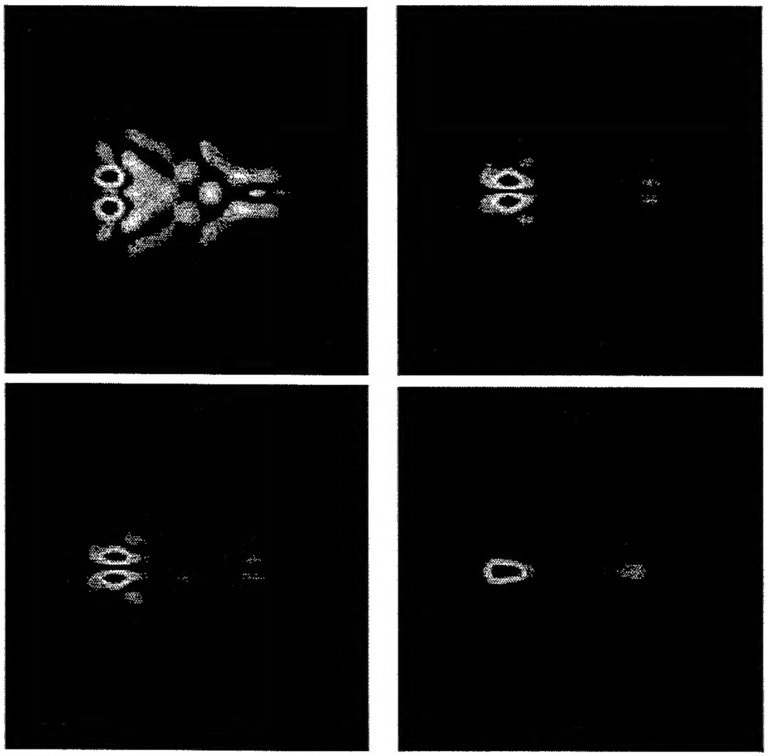

Figure 4: Holographic reconstruction of the VFY-218 from HH (upper left), HV and VH (lower left and upper right), and VV (lower right) polarized data.

We simulated data for a 180 degree aperture at frequencies from 55.25 MHz to 79.25 MHz with a 6 MHz spacing (corresponding to television channels 2 through 6) using FISC. Reconstructions from these data sets, using single polarizations, are shown in Figures 4 through 6 for the VFY-218, the Bat, and the Falcon 100. Figure 7 shows the result of combining the various polarizations. Here, the method of combination is dictated by the holographic algorithm.

In Figure 4, notice that the double-wing structure of the VFY-218 is clearly visible in the HH reconstruction, as are the rudder and cockpit in the VV reconstruction. Figure 5 nicely shows the triangular shape and double-rudder structure of the Bat. In Figure 6, the particular sweepback angle of the Falcon 100's wings can be readily seen in the VV reconstruction, and the VV image shows the rudder, cockpit, and engines.

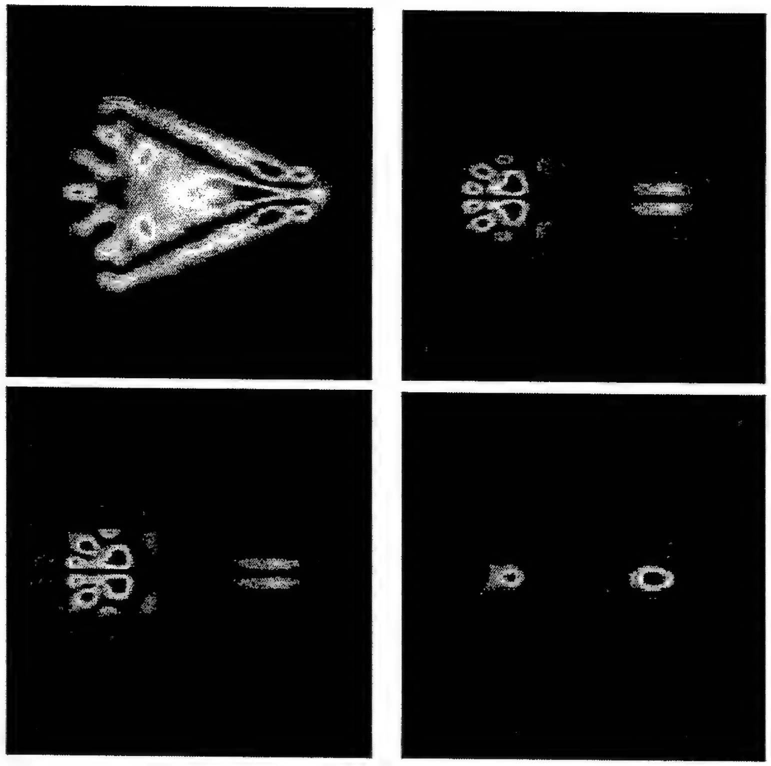

Figure 5: Holographic reconstruction of the Bat from HH (upper left), HV and VH (lower left and upper right), and VV (lower right) polarized data.

2.4 Nonlinear Inverse Scattering

Colton-Kirsch Linear Sampling Methods: A novel set of inverse scattering methods have appeared within the past few years in the applied mathematics literature. These so-called "sampling" methods have a certain characteristic structure: for a given sample point in the reconstruction domain, one performs a computation involving the measured scattering data and the location of that point; this computation results in a single number for that point. Depending on that number, the selected sample point is declared either "inside" or "outside" the scatterer boundary. Through our experiments with these new methods, we hope to introduce them to the mainstream electrical engineering audience. Unfortunately, the methods have a few limitations which currently limit their applicability to our passive radar problem: 1) they are for monofrequent excitation, whereas a radar system often involves several different frequencies, and 2) the range of observed angles needs to be the same as the range of incident angles. Modifications of the methods which relax these requirements would be quite helpful.

In the journal paper "A Comparison of the Colton-Kirsch Inverse Scattering Methods with Linearized Tomographic Inverse Scattering," provided in the appendix, we show results concerning the first of these methods, the "linear sampling" method developed by

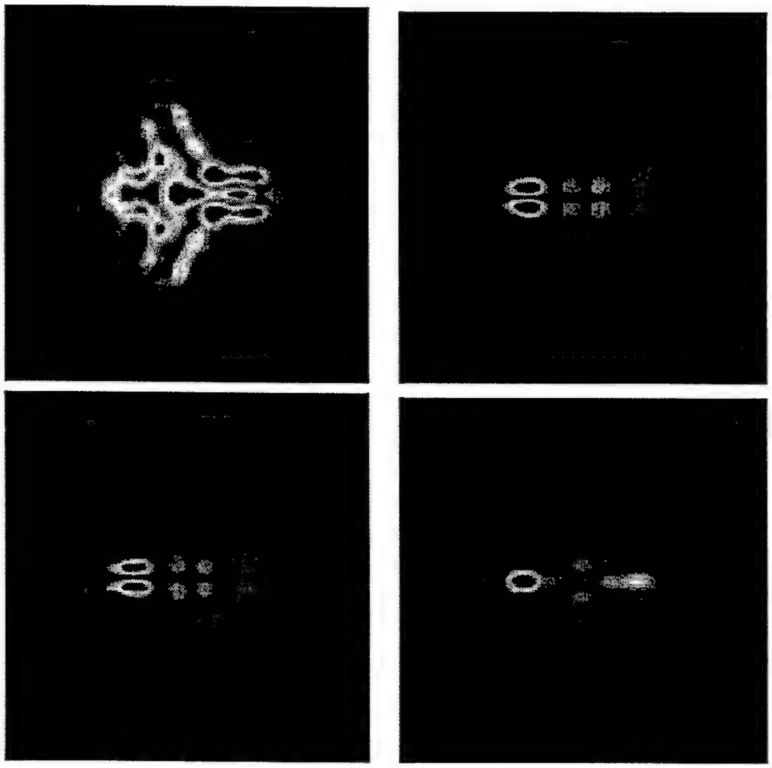

Figure 6: Holographic reconstruction of the Falcon 100 from HH (upper left), HV and VH (lower left and upper right), and VV (lower right) polarized data.

D. Colton and A. Kirsch and their colleagues [14, 15, 16, 17, 18, 19, 20, 21, 22]. The method consists of solving an equation of the form $Fg = f$, where F is an array of the scattering data and f is a matrix of complex exponentials which are a function of the sample point. Points where $\|g\|$ "blows up" are considered outside the scatterer. We compared reconstructions with the linear sampling technique with reconstructions formed by linearized tomographic inverse scattering algorithms. We observed unusual phenomena in the Colton-Kirsch reconstructions which do not seem to be well explained by the existing theory. We hope these numerical results will provide the impetus for further theoretical developments.

Kirsch's New Inverse Scattering Method: A. Kirsch has developed a new method which is similar in spirit to the "linear sampling" method described above. Instead of solving a linear equation at each sample point in the reconstruction domain, one solves a certain one-dimensional optimization problem, and then computes a certain quadratic form. If this quadratic form is nonzero, then the point is considered to be inside the scatterer.

We have implemented Kirch's new technique and are currently comparing it to both linear reconstruction methods and the earlier Colton-Kirsch methods. This is ongoing work. Some preliminary two-dimensional experiments are shown here. In these experi-

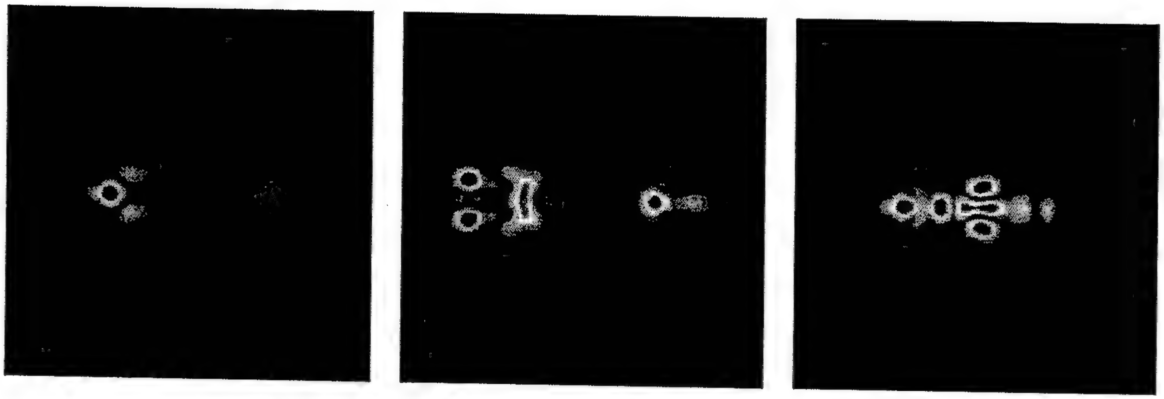

Figure 7: Holographic reconstruction of the VFY-218 (left), the Bat (center), and the Falcon 100 (right) using data for all polarizations.

ments, the object is taken to be an infinitely extended cylinder with profile given by one of the shapes in Fig. 8. We assume that a full circle of data, both in incident angle and observed angle, is available. The incident wave is either a traverse magnetic (TM) or traverse electric (TE) wave of either 100 or 200 MHz. The results are shown in Fig. 9.

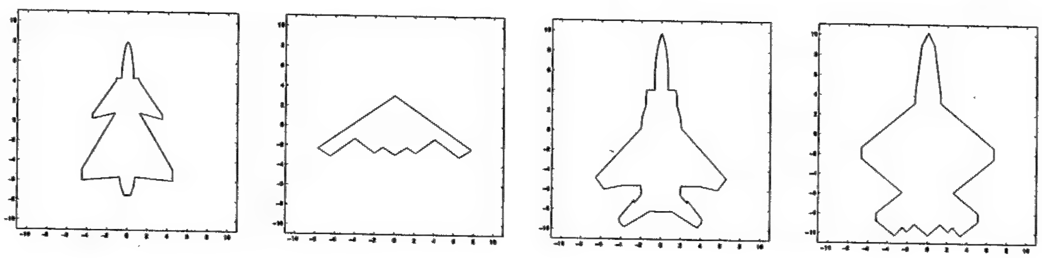

Figure 8: Boundaries of two-dimensional objects used in the simulations with Kirsch's new method. From left to right: VFY-218, B-2, F-15, and YF-23 shapes.

In our experiments with the original Colton-Kirsch linear sampling methods, we found some unusual behavior; in particular, we found the scatterer outline to be most evident where the norm of **g** was the smallest, instead of where it blew up. We found no such surprises with Kirsch's new method; it more or less seems to operate as advertised. Notice, however, that the method seems unable to reconstruct concave features; it seems to give the *convex hull* of the object.

Potthast has developed another set of methods in the same class [23] which would be interesting to explore.

Distorted Born Iterative Method: We have reconstructed 2-D airplane-like shapes in the pixel domain using the distorted Born iterative method, as applied to metallic scatters. Our solution incorporates fast electromagnetic solvers employing the multilevel fast multipole algorithm and half-quadratic regularization techniques to regularize the solution without smoothing across object boundaries. This work is archived in the journal paper

"A Multilevel Fast Multipole Based Approach for Efficient Reconstruction of Perfectly Conducting Scatterers" provided in the Appendix.

2.5 Shape Estimation (Performance Bounds and Algorithms)

Performance Bounds for Shape Estimation Problems: We have developed Cramér-Rao bounds on the ability to estimate the shapes of targets. Four papers in the appendix document this work. The published journal papers "Asymptotic Global Confidence Regions in Parametric Shape Estimation Problems" and "Cramér-Rao Bounds for 2-D Target Shape Estimation in Nonlinear Inverse Scattering Problems with Application to Passive Radar" respectively focus on underlying mathematical theory and its application to a full nonlinear electromagnetics model. The submitted journal paper "Cramér-Rao Bounds for Parametric Shape Estimation in Inverse Problems" studies its application to linear problems such as Fourier imaging. The theory is extended to three dimensions in "Global Confidence Regions for Parametric Surface Estimation."

Shape Estimation from Sparse Data: We have explored both level set ("A Self-Referencing Level-Set Method for Image Reconstruction from Sparse Fourier Samples") and parametric contour ("Complexity Regularized Shape Estimation from Noisy Fourier Data") methods for reconstructing images from the sparse Fourier data available in passive radar systems.

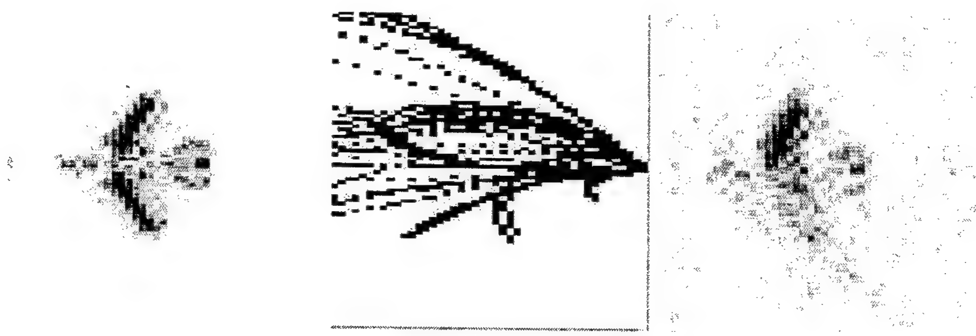

Figure 10: Left panel: Inversion of a full Fourier data set. Middle panel: Sampling pattern corresponding to a particular data collection scenario. Right panel: Inversion of a partial Fourier data set, corresponding to the sampling pattern shown in the middle panel.

Here we show a more recent example employing the level set method. The images displayed here are reconstructed from data generated by FISC for the Falcon. The left panel of Fig. 10 shows the result of inverting a full Fourier data set; such data cannot be collected in practice. The middle column of the same figure shows a Fourier sampling pattern corresponding to a physical flight path. (Our previous demonstrations of the level set techniques used a randomly generated sampling pattern for initial analysis of the algorithm's effectiveness.) Straightforward inversion of the partial data from this sampling pattern yields the blurry image shown in the right panel of Fig. 10.

A reconstruction using level set methods is shown in the top row of Fig. 11. When a particular axis of symmetry is known, the domain estimate evolution can be modified to

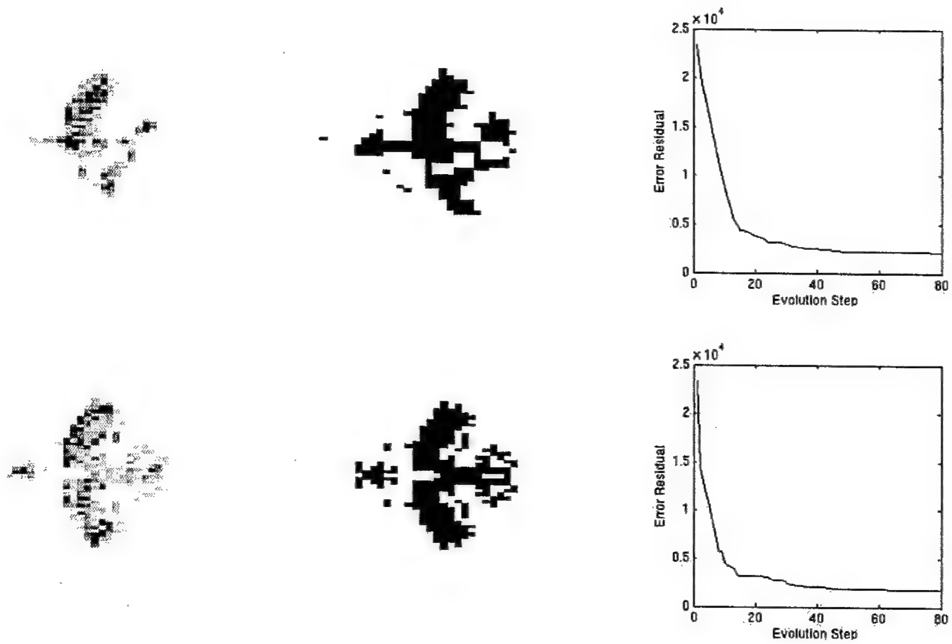

Figure 11: Results of level set algorithm. Top row shows original results; bottom row shows results where symmetry of the estimated domain (non-zero pixel set) is enforced. Left column: magnitude of estimated reflectivities. Middle column: estimated domain (set of non-zero pixels.) Right column: squared error as function of iteration.

take advantage of this fact. Such results are shown in the bottom row of Fig. 11. The incorporation of this symmetry results in an image that has a smaller final error residual (17% reduction from the previous case which has no symmetry axis), converges faster, and has more aesthetically pleasing results, with the wings and body of the plane more readily identifiable.

2.6 Fast Multilevel Transform Algorithms

Fast Backprojection Algorithms: FFT-based methods are commonly used in radar due to their computational efficiency. Backprojection offers several advantages over FFT methods: it accommodates a wider variety of autofocus algorithms, it is more natural for wide apertures, and can correctly accommodate near-field scenarios. Conventional backprojection, however, is significantly slower than its FFT-based counterparts. We have crafted novel recursive backprojection algorithms for both far-field and near-field SAR imaging, as described in the appendix in "An $N^2 \log N$ Back-Projection Algorithm for SAR Image Formation." The follow-up paper "A Fast Back-Projection Algorithm for Bistatic SAR Imaging" extends this work to the bistatic scenario which is more appropriate for passive radar.

Fast Fourier Transforms on Nonuniform Grids: Many areas of radar imaging

require transformation between spatial and frequency domains, where the data in both domains is nonuniform. We have developed fast Fourier transforms which can operate efficiently on such nonuniform data. These algorithms take on the spirit of the multilevel fast multipole methods used in codes such as FISC. The appended conference papers "Fast Fourier Transform of Sparse Spatial Data to Sparse Fourier Data" and "A Sparse Data Fast Fourier Transform (SDFFT) - Algorithm and Implementation" describe this work.

2.7 Interferometric SAR

We have computed optimal antenna spacings for active interferometric SAR using multiple antennas to eliminate ambiguities; this work documented in the appendix in the paper "Optimal Antenna Spacings in Inferferometric SAR." A revision of this paper is under preparation for submission to IEEE Trans. on Aerospace and Electronic Systems.

3 Suggestions for Other Areas of Future Work

Over the course of this work, it became apparent that there were many aspects of passive radar systems which would benefit from future research. Some of those areas are described here.

3.1 Multitarget-Multisensor Tracking Issues

Many of the usual issues and difficulties faced in target tracking applications get turned around when we move from active to passive radar. In many traditional passive tracking problems, such as sonar, emphasis is placed on tracking targets using angle measurements, with tracks often initialized via triangulation. In passive radar systems using television or FM radio signals, precise angle measurements are difficult to come by. Rough range measurements from FM radio may be used to initialize tracks via trilateration. The best information available is the Doppler shift associated with target velocity.

Numerous multitarget-multisensor tracking issues arise in such systems; the data association problem often becomes particularly difficult. The target tracking community seems to be converging upon "multiple frame assignment" using "Lagrangian relaxation" as one of the best ways to address the multitarget-multisensor problem. We are not aware of any existing work applying these methods to the passive radar problem. There seem to be two schools of thought on Lagrangian relaxation, one arising from the Univ. of Connecticut [24, 25, 26, 27], and the other from a Colorado State Univ. spinoff company called Numerica [28, 29].

3.2 Reducing Interference from Nearby Transmitters

The performance of any radar system is ultimately limited by the available signal-to-noise ratio. Some of the noise arises from galactic radiation and thermal noise in the receiver; there is little one can do about those nuisances. Another source in passive radar systems is out-of-band interference from the plethora of commercial transmitters. The FCC specifies that every station must have a broadcast power lower than a certain number of decibels outside a certain bandwidth; little else is said about what the transmitter does outside

of that. These "skirts" barely bother FM music reception, since the consumer's radio receiver is simply looking for a frequency-shifted carrier. However, the skirts from a large number of transmitters can create a nightmare for a passive radar system, since the reflected signal being sought is at the level of the skirts. An informal presentation by Dick Lodwig of Lockheed Martin Mission Systems at a meeting at the Air Force Institute of Technology suggested that successfully combating such "skirt" noise could potentially *double* the detection range of the Silent Sentry system.

3.3 Jamming

The role of jamming in PCL systems can be considered from two viewpoints; we may put ourselves the seat of a pilot attempting to infiltrate an area which might potentially be surveyed by a PCL system, or we may put ourselves in the position of engineers trying to design a PCL system to be resistant to jamming. One cannot fully attack the problem from one viewpoint without considering the other.

The countermeasure side – jamming a PCL system – is made more complicated by the fact that one does not know where the system is located, or what transmitters are being exploited. Finding optimal jamming strategies (a difficult problem, as the jammer often finds itself becoming a target in short order) is of vital importance to the U.S. Air Force, as many countries (both friendly and not so friendly) are suspected to be developing PCL technology.

The counter-countermeasure side – making a system resistant to jamming – is difficult due to the low signal strength of the signals bouncing off the aircraft of interest; raising the noise level at the receiver does not require an appreciable amount of power. A PCL system must be adaptive, able to determine that it is being jammed, and to switch to other transmitters and frequencies which are not being jammed. Architectural issues in terms of exploiting the diversity of data available from using multiple receivers will be particularly important. Another issue needing investigation is the often-made (but seldom rigorously backed up) claim that a PCL system can switch to using the jammer itself as a new illuminator of opportunity.

4 Personnel Supported

4.1 Faculty

- **Richard E. Blahut** (PI), Professor and Head of Electrical and Computer Engineering
- **Yoram Bresler**, Professor of Electrical and Computer Engineering
- **Weng C. Chew**, Professor of Electrical and Computer Engineering; Director of the Center for Computational Electromagnetics
- **Pierre Moulin** (co-PI), Associate Professor of Electrical and Computer Engineering
- **David C. Munson, Jr.**, Professor of Electrical and Computer Engineering

4.2 Postdocs

- **Michael Brandfass** worked primarily with Weng Chew. In September 2000, he joined AeroSensing, GmbH in Germany.

- **Aaron Lanterman** assisted with overall coordination of the project and was the primary point-of-contact for both DARPA and Lockheed Martin. In August 2001, he left UIUC to join the faculty of the School of Electrical Engineering at the Georgia Institute of Technology.

- **Natalia Schmid** joined the project in January 2001, after completing her doctorate at Washington University in St. Louis. She worked primarily with Yoram Bresler and Pierre Moulin on investigating problems of shape estimation from sparse Fourier data.

- **Sviatoslav Voloshynovskiy** worked primarily with Yoram Bresler and Pierre Moulin. He left UIUC in February of 1999 to accept a position at University of Geneva.

- **Jong Ye** joined UIUC in February of 1999 and worked primarily with Yoram Bresler and Pierre Moulin. He joined Polaroid at the beginning of 2001, and is currently with Phillips Research.

4.3 Graduate Students

- **Alaeddin Aydiner**, student of Weng Chew.

- **Jeffrey Brokish** is a PhD student of Yoram Bresler's. He joined the project in January of 2001 to continue Jong Ye's work on level set methods.

- **Yu Ding**, student of David Munson.

- **Shawn Herman** is expected to complete his PhD under Pierre Moulin in August 2003. He has accepted a position as a research scientist at Numerica, a company founded by Aubrey Poor to work on multitarget multisensor tracking algorithms.

- Air Force **Capt. Larkin Hastriter** is a doctoral student under Weng Chew. He served in an advisory role to the radar imaging and recognition project.

- **Soumya Jana**, doctoral student of Pierre Moulin.

- **Rob Morrison** is a master's student working under David Munson. He joined the project in January of 2001 to work on autofocus issues.

- **Raman Venkataramani** completed his PhD under Yoram Bresler.

- **Xinzhou Wu**, student of Weng Chew.

- **Yong Wu** completed his third year of PhD studies under David Munson; he has returned to Singapore to work in industry.

- **Shu Xiao** completed her PhD under David Munson.

4.4 Undergraduate Students

- **Amit Rana** was senior tasked with creating data sets using FISC in 2000.

5 Publications

5.1 Journal Publications

5.1.1 Published

- M. Brandfass, A.D. Lanterman, and K.F. Warnick, "A Comparison of the Colton-Kirsch Inverse Scattering Methods with Linearized Tomographic Inverse Scattering," *Inverse Problems*, Vol. 17, No. 6, Dec. 2001, pp. 1797-1816.
- M. Brandfass and W.C. Chew, "A Multilevel Fast Multipole Based Approach for Efficient Reconstruction of Perfectly Conducting Scatterers," *Journal of Electromagnetic Waves and Applications*, Vol. 55, No. 1, Jan. 2001, pp. 81-106.
- A.D. Lanterman, "Jump-Diffusion Algorithm for Multiple Target Recognition Using Laser Radar Range Data", *Optical Engineering*, Vol. 40, No. 8, August 2001, pp. 1724-1728.
- A.D. Lanterman, "Schwarz, Wallace, and Rissanen: Intertwining Themes in Theories of Model Order Estimation," *International Statistical Review*, Vol. 69, No. 2, August 2001, pp. 185-212.
- J. Liu and P. Moulin, "Statistical Imaging and Complexity Regularization," *IEEE Trans. on Information Theory*, Vol. 46, No. 5, August 2000, pp. 1726-1777.
- R. Venkataramani and Y. Bresler, "Optimal Sub-Nyquist Sampling and Reconstruction for Multiband Signals," *IEEE Trans. on Signal Processing*, Vol. 49, No. 10, Oct. 2001, pp. 2301-2313.
- R. Venkataramani and Y. Bresler, "Perfect Reconstuction Formulas and Bounds on the Aliasing Error in Sub-Nyquist Sampling of Multiband Signals," *IEEE Trans. on Information Theory*, Vol. 46, No. 6, Sept. 2000, pp. 2173-2183.
- J.C. Ye, Y. Bresler, and P. Moulin, "Cramér-Rao Bounds for 2-D Target Shape Estimation in Nonlinear Inverse Scattering Problems with Application to Passive Radar," *IEEE Trans. on Antennas and Propagation*, Vol. 49, No. 5, May 2001, pp. 771-783.
- J. Ye, Y. Bresler, and P. Moulin, "Asymptotic Global Confidence Regions in Parametric Shape Estimation Problems", *IEEE Trans. on Information Theory*, Vol. 46, No. 5, August 2000, pp. 1881-1895.

5.1.2 Accepted for Publication - In Press

- A. Jain, P. Moulin, M.I. Miller, and K. Ramchandran, "Information-Theoretic Bounds on Target Recognition Performance Based on Degraded Image Data," *IEEE Trans. on Pattern Analysis and Machine Intelligence*, accepted for publication, to appear 2002.

- J.C. Ye, Y. Bresler, and P. Moulin, "Cramer-Rao Bounds for Parametric Shape Estimation in Inverse Problems", *IEEE Trans. on Image Processing*, accepted for publication.

5.1.3 Submitted for Publication

- M. Brandfass, K.-J. Langenberg, and A. Rohrmoser, "Electromagnetic Diffraction Tomography in Angular Diversity Mode," submitted to *IEEE Trans. on Antennas and Propagation.*

- S. Jana and P. Moulin, "Optimal Design of Transform Coders for Joint Signal Classification and Compression," *IEEE Trans. on Information Theory*, to be submitted, May 2002.

- A.D. Lanterman, "Maximum-Likelihood Estimation for Hybrid Specular/Diffuse Models of Radar Imaging and Target Recognition," submitted to *IEEE Trans. on Aerospace and Electronic Systems*, May 2000.

- Y. Wu, A.D. Lanterman, and D.C. Munson, Jr., "Wide-Angle Radar Imaging using Wigner-Ville Distributions," currently under preparation. To be submitted to *IEE Proc. F: Radar, Sonar, and Navigation*, 2002.

- R. Venkataramani and Y. Bresler, "Filter Design for MIMO Sampling and Reconstruction", submitted to *IEEE Trans. on Signal Processing*, Jan. 2002.

- R. Venkataramani and Y. Bresler, "MIMO Sampling: Necessary Density Conditions," submitted to *IEEE Trans. on Information Theory*, Dec. 2001.

- R. Venkataramani and Y. Bresler, "Sampling Theorems for Uniform and Periodic Nonuniform MIMO Sampling of Multiband Signals," submitted to *IEEE Trans. on Signal Processing*, Dec. 2001.

- J.C. Ye, Y. Bresler, and P. Moulin, "Global Confidence Regions for Parametric Surface Estimation," invited paper, submitted to *International Journal of Computer Vision*, April 2001.

5.2 Dissertations

- S. Herman, "Nonlinear Filtering Techniques for FM-Band Passive Radar Tracking and Automatic Target Recognition," PhD thesis, Univ. of Illinois at Urbana-Champaign, anticipated Aug. 2002.

- R. Venkataramani, "Sub-Nyquist Multicoset and MIMO Sampling: Perfect Reconstruction, Performance Analysis, and Necessary Density Conditions," PhD thesis, Univ. of Illinois at Urbana-Champaign, Dec. 2001.

- S. Xiao, "Topics in CT and SAR Imaging: Fast Back-Projection Algorithms and Optimal Antenna Spacings," PhD thesis, Univ. of Illinois at Urbana-Champaign, Feb. 2001

5.3 Conference Publications

- A.A. Aydiner, W.C. Chew, J. Song, "A Sparse Data Fast Fourier Transform (SDFFT) - Algorithm and Implementation," *IEEE Antenna and Propagation International Symposium*, Vol. 4, July 2001, pp. 638-641.

- M. Brandfass and W.C. Chew, "Microwave imaging as applied to remote sensing making use of a multilevel fast multipole algorithm," in *Algorithms for Synthetic Aperture Radar Imagery VII*, Proc. SPIE 4053, Ed: E.G. Zelnio, Orlando, FL, April 2000, pp. 52-63.

- Y. Bresler, M. Gastpar, and R. Venkataramani, "Image Compression On-The-Fly by Universal Sampling in Fourier Imaging Systems," *Proc. 1999 IEEE Information Theory Workshop on Detection, Estimation, Classification, and Imaging*, Santa Fe, NM, February 1999.

- W.C. Chew and J.M. Song, "Fast Fourier Transform of Sparse Spatial Data to Sparse Fourier Data," *IEEE Antenna and Propagation International Symposium*, Vol. 4, July 2000, pp. 2324-2327.

- M.D. DeVore, A.D. Lanterman, J.A. O'Sullivan, "ATR Performance of a Rician Model for SAR Images," in *Automatic Target Recognition X*, Proc. SPIE 4050, Ed: E.G. Zelnio, Orlando, FL, April 2000, pp. 34-45.

- Y. Ding and D.C. Munson, Jr., "A Fast Back-Projection Algorithm for Bistatic SAR Imaging," *Proc. IEEE International Conference on Image Processing*, Rochester, NY, Sept. 22-25, 2002.

- S.C. Herman and P. Moulin, "A Particle Filtering Approach to Joint Radar Tracking and Automatic Target Recognition", *Proc. IEEE Aerospace Conference*, Big Sky, Montana, March 10-15, 2002.

- A. Jain, P. Moulin, M.I. Miller, and K. Ramchandran, "Information-Theoretic Bounds on Target Recognition Performance," in *Automatic Target Recognition X*, Proc. SPIE 4050, Ed: F.A. Sadjadi, Orlando, FL, April 2000, pp. 347-358.

- S. Jana and P. Moulin, "Optimal Design of Transform Coders and Quantizers for Image Classification," *IEEE International Conference on Image Processing*, Vancouver, Canada, Sept. 10-13, 2000.

- S. Jana and P. Moulin, "Optimal Design of Transform Coders for Image Classification," *Proc. Conf. on Information Sciences and Systems*, Baltimore, MD, March 1999.

- A.D. Lanterman, "Deconvolution Techniques for Passive Radar Imaging," in *Algorithms for Synthetic Aperture Radar Imagery IX*, Proc. SPIE 4727, Ed: E.G. Zelnio, Orlando, FL, April 2002.

- A.D. Lanterman, "Efficient implementation of an expectation-maximization algorithm for imaging diffuse radar targets," in *Algorithms for Synthetic Aperture Radar Imagery VIII*, Proc. SPIE 4382, Ed: E.G. Zelnio, Orlando, FL, April 2001.

- A.D. Lanterman, "Statistical Radar Imaging of Diffuse and Specular Targets Using an Expectation-Maximization Algorithm," in *Algorithms for Synthetic Aperture Radar Imagery VII*, Proc. SPIE 4053, Ed: E.G. Zelnio, Orlando, FL, April 2000, pp. 20-31.

- A.D. Lanterman, "Tracking and recognition of airborne targets via commercial television and FM radio signals," *Acquisition, Tracking, and Pointing XIII*, Proc. SPIE 3692, Orlando, FL, April 1999.

- A.D. Lanterman, "Radar Imaging with Variations of an Expectation-Maximization Algorithm," *Proc. 1999 IEEE Workshop on Detection, Estimation, Classification, and Imaging*, Santa Fe, NM, February 1999, p. 51.

- R.L. Morrison, Jr. and D.C. Munson, Jr., "An Experimental Study of a New Entropy-Based SAR Autofocus Technique," *Proc. of the IEEE International Conference on Image Processing*, Rochester, NY, Sept. 22-25, 2002, to appear.

- D.W. Rieken, A.D. Lanterman, and D.R. Fuhrmann, "Spatial Spectrum Estimation for Time-Varying Arrays Using the EM Algorithm," *38th Allerton Conference on Communication, Control, and Computing*, October 4-6, 2000.

- N. Schmid, Y. Bresler, P. Moulin, "Complexity Regularized Shape Estimation from Noisy Fourier Data," *Proc. IEEE International Conference on Image Processing*, Rochester, NY, Sept. 2002.

- Y. Wu, D.C. Munson, Jr., and A.D. Lanterman, "Multistatic Passive Radar Imaging of Aircraft: A Feasibility Study Using FISC," *Proc. URSI National Radio Science Meeting, Boulder*, CO, Jan. 9-12, 2002.

- Y. Wu and D.C. Munson, Jr., "Multistatic Passive Radar Imaging Using the Smoothed Wigner-Ville Distribution," *Proc. of the IEEE International Conference on Image Processing*, Thesaloniki, Greece, Oct. 2001.

- Y. Wu and D.C. Munson, Jr., "Wide-Angle L-Band ISAR Imaging Using the Wigner-Ville Distribution," *IEEE Radar Conference*, Atlanta, GA, May 1-3, 2001.

- Y. Wu and D.C Munson, Jr., "Multistatic Synthetic Aperture Imaging of Aircraft using Reflected Television Signals," in *Algorithms for Synthetic Aperture Radar Imagery VIII*, Proc. SPIE 4382, Ed: E.G. Zelnio, Orlando, FL, April 2001.

- R. Venkataramani and Y. Bresler, "Necessary Conditions for MIMO Sampling of Multiband Inputs", *Proc. International Symposium on Information Theory*, Lausanne, Switzerland, June 2002.

- S. Xiao, Y. Bresler, and D.C. Munson, "$O(N^2 \log N)$ Native Fan-Beam Tomographic Reconstruction," *Proc. of the First IEEE International Symposium on Biomedical Imaging*, Washington, DC, July 2002.

- S. Xiao, D.C. Munson, S. Basu, Y. Bresler, "An $N^2 \log N$ back-projection algorithm for SAR image formation," *Proc. 34th Asilomar Conf. on Signals, Systems, and Computers*, Pacific Grove, CA, Oct. 31 - Nov. 1, 2000.

- S. Xiao and D. Munson, "Optimal Antenna Spacings in Interferometric SAR," in *Algorithms for Synthetic Aperture Radar Imagery VII*, Proc. SPIE 4053, Ed: E.G. Zelnio, Orlando, FL, April 2000, to appear.

- J.C. Ye, Y. Bresler, and P. Moulin, "A Self-Referencing Level-Set Method for Image Reconstruction from Sparse Fourier Samples," *IEEE Workshop on Variational and Level Set Methods in Computer Vision*, Vancouver, CA, July 2001; also Proc. of the IEEE International Conference on Image Processing, Thesaloniki, Greece, Oct. 2001.

- J.C. Ye, Y. Bresler, and P. Moulin, "Global Confidence Regions in Parametric Shape Estimation," *IEEE International Conference on Acoustics, Speech, and Signal Processing*, 2000, Turkey.

- J.C. Ye, Y. Bresler and P. Moulin, "Fourier Descriptors for Parametric Shape Estimation in Nonlinear Inverse Scattering Problems," *Signal Processing, Sensor Fusion, and Target Recognition IX*, Proc. SPIE 4052, Ed: I. Kadar, Orlando, FL, April 2000, pp. 309-320.

5.4 Book Chapters

- A.D. Lanterman, "Statistical Imaging in Radio Astronomy via an Expectation-Maximization Algorithm for Structured Covariance Estimation," in *Statistical Methods in Imaging: In Medicine, Optics, and Communication*, a festschrift in honor of Donald L. Snyder's 65th birthday, Ed. J.A. O'Sullivan (Washington Univ.), Springer-Verlag, to appear.

- A. Srivastava, A.D. Lanterman, U. Grenander, M. Loizeaux, M.I. Miller, "Monte-Carlo Techniques for Automated Target Recognition," in *Sequential Monte Carlo Methods in Practice*, Chapter 26, Eds: N. de Freitas (Univ. of Cambridge), Arnaud Doucet (Univ. of Cambridge), and Neil Gordon (U.K. Defence Research Agency), Springer-Verlag, pp. 533-552, 2001.

6 Interactions/Transitions

6.1 Interactions with Government Organizations and Lockheed-Martin

- Aaron Lanterman presented a project review as part of the PCL Intelligence Conference at the Defense Intelligence Agency on August 7-8, 2001.

- Aaron Lanterman presented project reviews at three *DARPA ACMP Principal Investigators Meetings*: Strategic Analysis in Arlington, VA, April 4-6, 2001 and April 17-19, 2000, and in San Francisco, CA, June 30-July 1, 1999.

- On June 7-8, 2001, Shawn Herman, Rob Morrison, David Munson, and Aaron Lanterman attended and presented material at a two-day workshop on passive radar at the Air Force Institute of Technology (Dayton, OH) organized by AFIT Prof. Andy Terzouli. Other participants included Nick Willis (formerly of DARPA and Technology Service Corporation), Bob Ogrodnik (Air Force Research Lab, Rome), Dick Lodwig (Lockheed Martin Mission Systems), and Larkin Hastriter (U.S. Air Force). We helped advise six masters students on thesis topics relating to passive radar. The students were F-16 pilots on a NATO exchange program. Five were from Turkey; one was from Chile. In February 2001, Aaron Lanterman had a separate meeting with the AFIT group in Dayton to begin the collaboration.

- Beginning in September, 2000, Aaron Lanterman served on a Scientific Advisory Panel on Passive Coherent Location (PCL) systems. The panel, organized through The MITRE Co., was sponsored by Dr. Ron Pandolfi of the National Intelligence Council (NIC), and reported to Maj. Gen. John Landry (Ret.), the National Intelligence Officer for Conventional Military Issues. The final briefing to Gen. Landry took place on April 3-4, 2001, in McLean, VA. Other panel members included Nick Willis, Dick Lodwig, Scott Kordella (MITRE), David Barton (formerly with Raytheon), Al Bernard (Lincoln Labs), and John Sahr (Univ. of Washington). Panel members received a Certificate of Excellence Certificate of Excellence for "outstanding contributions to the National Intelligence Council and exceptional service to the Intelligence Community" for this work. In July, 2002, Aaron Lanterman will begin serving on a follow-up effort, also sponsored by NIC through MITRE, called the Air and Missile Defense Advisory Panel (AMDAP).

6.1.1 Meetings at Lockheed-Martin Mission Systems

The following meetings took place at Lockheed-Martin Mission Systems in Gaithersburg, MD:

- January 29, 1999: Six member of the UIUC group, Yoram Bresler, Pierre Moulin, David Munson, Shawn Herman, Aaron Lanterman, and Ana Martinez visited the PCL group at Lockheed-Martin Mission Systems. Lockheed Martin gave a demonstration of their Silent Sentry System.

- October 19, 1999: Lockheed Martin hosted the second project review for DARPA. Six members of the UIUC group, Richard Blahut, Yoram Bresler, Pierre Moulin, David Munson, Shawn Herman and Aaron Lanterman, were in attendance.

- April 12, 2001: Visit by Shawn Herman, Rob Morrison, David Munson, and Aaron Lanterman from the UIUC group.

6.1.2 Visits to UIUC by Lockheed Martin and DARPA Personnel

- May, 1998: Initial kickoff meeting with Dick Lodwig and Kevin Baugh (Lockheed Martin).

- November 11, 1998: Visit by Robert Taylor of Lockheed Martin Mission Systems.

- April 17, 1999: First site visit to UIUC by Dennis Healy (DARPA). Robert Taylor (Lockheed Martin) attended as well.

- March 9, 2000: Visit by Bert Bradford (Lockheed Martin).

- February 6, 2001: Visit by Bert Bradford (Lockheed Martin).

6.1.3 Internships

Shawn Herman joined Lockheed Martin Mission Systems for two six-week summer internships in 1999 (starting June 28) and 2000 (starting August 22). The first internship focused on scattering database generation using FISC. The second focused on two areas: 1) methods for compressing large scattering databases of aircraft, and 2) understanding bistatic low-frequency scattering of faceted targets.

6.2 Other Participation/Presentations at Meetings and Conferences

- Weng Chew presented a paper at the IEEE Antenna and Propagation International Symposium, July, 2000.

- Shawn Herman gave a presentation titled "A Particle Filtering Approach to Joint Radar Tracking and Automatic Target Recognition" at the First Annual ATR Theory Workshop at Wright State University, August 8-9, 2001.

- Yong Wu and Aaron Lanterman presented papers in the Algorithms for Synthetic Aperture Radar Imagery VIII conference at *SPIE AeroSense*, Orlando, FL, April 16-20, 2001.

- Aaron Lanterman assembled and chaired a session on "Information Theory and ATR" in the Automatic Target Recognition XI (April 16-20, 2001) and X (April 24-28, 2000) conferences at *SPIE AeroSense*, Orlando, FL. He also presented a paper on radio astronomy at the *URSI National Radio Science Meeting*, January 4-8, 2000, Boulder, CO.

- Yoram Bresler, Pierre Moulin, and David Munson, presented papers at the IEEE International Conference on Image Processing, Thesaloniki, Greece, Oct. 2001

- David Munson presented a paper at and the IEEE Radar Conference, Atlanta, GA, May 1-3, 2001.

- Shu Xiao presented a paper at the Asilomar Conf. on Signals, Systems, Systems, and Computers, Pacific Grove, CA, Oct. 31-Nov. 1.

- Yoram Bresler presented a paper at the IEEE Workshop on Variational and Level Set Methods of Computer Vision, Vancouver, CA, July 2001.

- Shawn Herman and Aaron Lanterman attended the *EMCC (Electromagnetic Code Consortium) Annual Meeting and HPC/MURI Project Reviews* at Boeing Phantom Works, St. Louis, MO, May 8-12, 2000.

- Yoram Bresler presented work on global confidence regions at the *IEEE International Conference on Acoustics, Speech, and Signal Processing*, Istanbul, Turkey 2000.

- Michael Brandfass (distorted Born methods), Pierre Moulin (performance bounds for ATR), Jong Ye (global confidence regions), Aaron Lanterman, and David Munson (two presentations, one on interferometric antenna spacings, the other a plenary talk on radar) gave presentations at *SPIE AeroSense*, April 24-28, 2000, Orlando, FL.

- David Munson attended the *IEEE International Conference on Image Processing*, October 24-27, 1999, Kobe, Japan; the *Integrated Imaging Workshop*, December 16, 1999, Army Research Office, Research Triangle, NC; the *IEEE Sensor Array and Multichannel Signal Processing Workshop*, March 16-17, 2000, Cambridge, MA; and the *IEEE International Conference on Acoustics, Speech, and Signal Processing*, June 5-9, 2000, Istanbul, Turkey.

- Weng Chew attended the *AFOSR Electromagnetics Workshop*, January 6-9, 1999, San Antonio, TX; presented a paper at the *PIERS Conference*, March 20-27, 1999, Taipei, Taiwan; attended the *TBM Signatures Conference*, May 26-28, 1999, Huntsville, AL; visited NSF, AFOSR, and DARPA in Washington, DC during June 22-25, 1999; gave a presentation at the *30th AIAA Plasmadynamics and Laser Conference*, June 28-July 1, 1999, Norfolk, VA; and presented a paper at the *IEEE AP-S/URSI International Symposium*, July 10-15, 1999, Orlando, FL.

- Pierre Moulin co-chaired the *IEEE Workshop on Detection, Estimation, Classification, and Imaging*, February 24-26, 1999, Sante Fe, NM; co-organized the *IEEE International Conference on Image Processing*, October 4-7, 1998, Chicago, IL; and presented a paper at the *Conference on Information Sciences and Systems*, March 1999, Baltimore, MD.

- David Munson attended the *IEEE International Conference on Image Processing*, October 4-7, 1998, Chicago, IL; the *IEEE International Conference on Acoustics, Speech, and Signal Processing*, March 14-18, 1999, Phoenix, AZ; the *IEEE Radar Conference*, April 20-22, 1999, Waltham, MA; and the *DSPSCA Workshop*, July 7-9, University of Virginia, Charlottesville, VA.

- Aaron Lanterman presented two papers at *SPIE AeroSense*, April 5-9, 1999, Orlando, FL and presented a poster at the *IEEE Workshop on Detection, Estimation, Classification, and Imaging*, February 24-26, 1999, Sante Fe, NM.

- Aaron Lanterman and Sviatoslav Voloshynovskiy attended the *IEEE International Conference on Image Processing*, October 4-7, 1998, Chicago, IL.

- Shawn Herman and Jong Ye attended the *IEEE Workshop on Detection, Estimation, Classification, and Imaging*, February 24-26, 1999, Sante Fe, NM.

6.3 Visitors

- Upon the advice of Arje Nachman of AFOSR, **David Colton** (Mathematical Sciences, Univ. of Delaware) visited UIUC to present work on "linear sampling" methods of nonlinear inverse scattering and discuss potential areas of collaboration on January 24, 2000. This meeting resulted in work on a paper co-authored by Michael Brandfass, Aaron Lanterman, and Karl Warnick which has appeared in Inverse Problems.

- **Hao Ling** (Univ. of Texas at Austin) presented work on scattering center representations for radar signatures on February 4, 1999.

- **Lee Potter** (Ohio State University) presented work on scattering center representations and ultrawideband radar on March 23, 1999.

- **Joseph A. O'Sullivan** (Washington Univ. in St. Louis) visited to discuss work on exploiting statistical models for radar data in formulating ATR algorithms for the DARPA MSTAR data set on June 4, 1999.

7 New Discoveries, Inventions, or Patent Disclosures

Shu Xiao, Yoram Bresler, and David C. Munson, Jr., "Fast Native Divergent-Beam Reconstruction Algorithms for Tomography," Invention Disclosure, Feb. 26, 2002, University of Illinois, Urbana, IL. Patent application under preparation.

8 Honors/Awards

- **Yoram Bresler** was named an IEEE Fellow in January 1999 "for contributions to computer based imaging and sensor array processing." He is the recipient of two Senior (Best Paper) awards of the IEEE Acoustics, Speech, and Signal Processing Society in 1988 and 1989, and was a coauthor of a paper awarded a Best Young Author award by the same society in 2002. He received a 1991 Presidential Young Investigator Award of the National Science Foundation, a 1995-6 Technion (Israel) Fellowship, and a 1998 Xerox Senior Award for Faculty Research. In 1999 he was named a University of Illinois Scholar, and was appointed an Associate at the University of Illinois Center for Advanced Study in 2001-2.

- **Richard E. Blahut** was named a Fellow of the IBM Corporation in 1980, a member of the National Academy of Engineering in 1990, and an IEEE Fellow in 1991. He received the IEEE Alexander Graham Bell Medal in 1998. In 2001, he became Head of the Department of Electrical and Computer Engineering at the Univ. of Illinois.

- **Weng C. Chew** was named an IEEE Fellow in 1993 and has received the IEEE Graduate Teaching Award. He received Founder Professorship from the College of Engineering of the Univ. of Illinois. He received the UIUC Campus Wide Professional and Graduate Teaching Award in 2001 and the S.A. Schelkunoff Best Paper Award (coauthored with J.S. Zhao) for a paper published in the IEEE Transactions on Antennas and Propagation in 2001. Recently, he has been elected by ISA Citations to the category of Most Highly Cited Authors (belonging to the top 0.5 percent).

- **Aaron D. Lanterman** joined the faculty of the School of Electrical and Computer Engineering at the Georgia Institute of Technology as an Assistant Professor in August, 2001. In September 2001, he received the Certificate of Excellence from the National Intelligence Council for "outstanding contributions to the National Intelligence Council and exceptional service to the Intelligence Community" for consulting work related to passive radar systems.

- **David C. Munson, Jr.** was named an IEEE Fellow in 1991 and was the Founding Editor-in-Chief of the IEEE Transactions on Imaging Processing. In 1998 he received the newly established Outstanding Teaching Award for Faculty in the Department of Electrical and Computer Engineering at the University of Illinois. In Fall 1999 he was the Texas Instruments Visiting Professor at Rice University. In 2000-2001, he was a Distinguished Lecturer of the IEEE Signal Processing Society, and in 2001 he was named the Robert C. MacClinchie Distinguished Professor of Electrical and Computer Engineering at the University of Illinois.

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9 Appendix

This appendix contains the following selected papers. Full references are available in the Publications section. The titles are given here to facilitate rapid location of specific papers, and ensure that the report is complete.

- "A Particle Filtering Approach to FM-Band Passive Radar Tracking and Automatic Target Recognition"
- "Deconvolution Techniques for Passive Radar Imaging"
- "Wide-Angle Radar Imaging using Wigner-Ville Distributions"
- "An Experimental Study of a New Entropy-Based SAR Autofocus Technique"
- "Efficient Implementation of an Expectation-Maximization Algorithm for Imaging Diffuse Radar Targets"
- "A Comparison of the Colton-Kirsch Inverse Scattering Methods with Linearized Tomographic Inverse Scattering"
- "A Multilevel Fast Multipole Based Approach for Efficient Reconstruction of Perfectly Conducting Scatterers"
- "Asymptotic Global Confidence Regions in Parametric Shape Estimation Problems"
- "Cramér-Rao Bounds for 2-D Target Shape Estimation in Nonlinear Inverse Scattering Problems with Application to Passive Radar"
- "Cramér-Rao Bounds for Parametric Shape Estimation in Inverse Problems"
- "Global Confidence Regions for Parametric Surface Estimation"
- "A Self-Referencing Level-Set Method for Image Reconstruction from Sparse Fourier Samples"
- "Complexity Regularized Shape Estimation from Noisy Fourier Data"
- "An $N^2 \log N$ Back-Projection Algorithm for SAR Image Formation"
- "A Fast Back-Projection Algorithm for Bistatic SAR Imaging"
- "Fast Fourier Transform of Sparse Spatial Data to Sparse Fourier Data"
- "A Sparse Data Fast Fourier Transform (SDFFT) - Algorithm and Implementation"
- "Optimal Antenna Spacings in Inferferometric SAR"

- R. Venkataramani, "Sub-Nyquist Multicoset and MIMO Sampling: Perfect Reconstruction, Performance Analysis, and Necessary Density Conditions," PhD thesis, Univ. of Illinois at Urbana-Champaign, Dec. 2001.

- S. Xiao, "Topics in CT and SAR Imaging: Fast Back-Projection Algorithms and Optimal Antenna Spacings," PhD thesis, Univ. of Illinois at Urbana-Champaign, Feb. 2001

5.3 Conference Publications

- A.A. Aydiner, W.C. Chew, J. Song, "A Sparse Data Fast Fourier Transform (SDFFT) - Algorithm and Implementation," *IEEE Antenna and Propagation International Symposium*, Vol. 4, July 2001, pp. 638-641.

- M. Brandfass and W.C. Chew, "Microwave imaging as applied to remote sensing making use of a multilevel fast multipole algorithm," in *Algorithms for Synthetic Aperture Radar Imagery VII*, Proc. SPIE 4053, Ed: E.G. Zelnio, Orlando, FL, April 2000, pp. 52-63.

- Y. Bresler, M. Gastpar, and R. Venkataramani, "Image Compression On-The-Fly by Universal Sampling in Fourier Imaging Systems," *Proc. 1999 IEEE Information Theory Workshop on Detection, Estimation, Classification, and Imaging*, Santa Fe, NM, February 1999.

- W.C. Chew and J.M. Song, "Fast Fourier Transform of Sparse Spatial Data to Sparse Fourier Data," *IEEE Antenna and Propagation International Symposium*, Vol. 4, July 2000, pp. 2324-2327.

- M.D. DeVore, A.D. Lanterman, J.A. O'Sullivan, "ATR Performance of a Rician Model for SAR Images," in *Automatic Target Recognition X*, Proc. SPIE 4050, Ed: E.G. Zelnio, Orlando, FL, April 2000, pp. 34-45.

- Y. Ding and D.C. Munson, Jr., "A Fast Back-Projection Algorithm for Bistatic SAR Imaging," *Proc. IEEE International Conference on Image Processing*, Rochester, NY, Sept. 22-25, 2002.

- S.C. Herman and P. Moulin, "A Particle Filtering Approach to Joint Radar Tracking and Automatic Target Recognition", *Proc. IEEE Aerospace Conference*, Big Sky, Montana, March 10-15, 2002.

- A. Jain, P. Moulin, M.I. Miller, and K. Ramchandran, "Information-Theoretic Bounds on Target Recognition Performance," in *Automatic Target Recognition X*, Proc. SPIE 4050, Ed: F.A. Sadjadi, Orlando, FL, April 2000, pp. 347-358.

- S. Jana and P. Moulin, "Optimal Design of Transform Coders and Quantizers for Image Classification," *IEEE International Conference on Image Processing*, Vancouver, Canada, Sept. 10-13, 2000.

- S. Jana and P. Moulin, "Optimal Design of Transform Coders for Image Classification," *Proc. Conf. on Information Sciences and Systems*, Baltimore, MD, March 1999.

- A.D. Lanterman, "Deconvolution Techniques for Passive Radar Imaging," in *Algorithms for Synthetic Aperture Radar Imagery IX*, Proc. SPIE 4727, Ed: E.G. Zelnio, Orlando, FL, April 2002.

- A.D. Lanterman, "Efficient implementation of an expectation-maximization algorithm for imaging diffuse radar targets," in *Algorithms for Synthetic Aperture Radar Imagery VIII*, Proc. SPIE 4382, Ed: E.G. Zelnio, Orlando, FL, April 2001.

- A.D. Lanterman, "Statistical Radar Imaging of Diffuse and Specular Targets Using an Expectation-Maximization Algorithm," in *Algorithms for Synthetic Aperture Radar Imagery VII*, Proc. SPIE 4053, Ed: E.G. Zelnio, Orlando, FL, April 2000, pp. 20-31.

- A.D. Lanterman, "Tracking and recognition of airborne targets via commercial television and FM radio signals," *Acquisition, Tracking, and Pointing XIII*, Proc. SPIE 3692, Orlando, FL, April 1999.

- A.D. Lanterman, "Radar Imaging with Variations of an Expectation-Maximization Algorithm," *Proc. 1999 IEEE Workshop on Detection, Estimation, Classification, and Imaging*, Santa Fe, NM, February 1999, p. 51.

- R.L. Morrison, Jr. and D.C. Munson, Jr., "An Experimental Study of a New Entropy-Based SAR Autofocus Technique," *Proc. of the IEEE International Conference on Image Processing*, Rochester, NY, Sept. 22-25, 2002, to appear.

- D.W. Rieken, A.D. Lanterman, and D.R. Fuhrmann, "Spatial Spectrum Estimation for Time-Varying Arrays Using the EM Algorithm," *38th Allerton Conference on Communication, Control, and Computing*, October 4-6, 2000.

- N. Schmid, Y. Bresler, P. Moulin, "Complexity Regularized Shape Estimation from Noisy Fourier Data," *Proc. IEEE International Conference on Image Processing*, Rochester, NY, Sept. 2002.

- Y. Wu, D.C. Munson, Jr., and A.D. Lanterman, "Multistatic Passive Radar Imaging of Aircraft: A Feasibility Study Using FISC," *Proc. URSI National Radio Science Meeting, Boulder*, CO, Jan. 9-12, 2002.

- Y. Wu and D.C. Munson, Jr., "Multistatic Passive Radar Imaging Using the Smoothed Wigner-Ville Distribution," *Proc. of the IEEE International Conference on Image Processing*, Thesaloniki, Greece, Oct. 2001.

- Y. Wu and D.C. Munson, Jr., "Wide-Angle L-Band ISAR Imaging Using the Wigner-Ville Distribution," *IEEE Radar Conference*, Atlanta, GA, May 1-3, 2001.

- Y. Wu and D.C Munson, Jr., "Multistatic Synthetic Aperture Imaging of Aircraft using Reflected Television Signals," in *Algorithms for Synthetic Aperture Radar Imagery VIII*, Proc. SPIE 4382, Ed: E.G. Zelnio, Orlando, FL, April 2001.

- R. Venkataramani and Y. Bresler, "Necessary Conditions for MIMO Sampling of Multiband Inputs", *Proc. International Symposium on Information Theory*, Lausanne, Switzerland, June 2002.

- S. Xiao, Y. Bresler, and D.C. Munson, "$O(N^2 \log N)$ Native Fan-Beam Tomographic Reconstruction," *Proc. of the First IEEE International Symposium on Biomedical Imaging*, Washington, DC, July 2002.

- S. Xiao, D.C. Munson, S. Basu, Y. Bresler, "An $N^2 \log N$ back-projection algorithm for SAR image formation," *Proc. 34th Asilomar Conf. on Signals, Systems, and Computers*, Pacific Grove, CA, Oct. 31 - Nov. 1, 2000.

- S. Xiao and D. Munson, "Optimal Antenna Spacings in Interferometric SAR," in *Algorithms for Synthetic Aperture Radar Imagery VII*, Proc. SPIE 4053, Ed: E.G. Zelnio, Orlando, FL, April 2000, to appear.

- J.C. Ye, Y. Bresler, and P. Moulin, "A Self-Referencing Level-Set Method for Image Reconstruction from Sparse Fourier Samples," *IEEE Workshop on Variational and Level Set Methods in Computer Vision*, Vancouver, CA, July 2001; also Proc. of the IEEE International Conference on Image Processing, Thesaloniki, Greece, Oct. 2001.

- J.C. Ye, Y. Bresler, and P. Moulin, "Global Confidence Regions in Parametric Shape Estimation," *IEEE International Conference on Acoustics, Speech, and Signal Processing*, 2000, Turkey.

- J.C. Ye, Y. Bresler and P. Moulin, "Fourier Descriptors for Parametric Shape Estimation in Nonlinear Inverse Scattering Problems," *Signal Processing, Sensor Fusion, and Target Recognition IX*, Proc. SPIE 4052, Ed: I. Kadar, Orlando, FL, April 2000, pp. 309-320.

5.4 Book Chapters

- A.D. Lanterman, "Statistical Imaging in Radio Astronomy via an Expectation-Maximization Algorithm for Structured Covariance Estimation," in *Statistical Methods in Imaging: In Medicine, Optics, and Communication*, a festschrift in honor of Donald L. Snyder's 65th birthday, Ed. J.A. O'Sullivan (Washington Univ.), Springer-Verlag, to appear.

- A. Srivastava, A.D. Lanterman, U. Grenander, M. Loizeaux, M.I. Miller, "Monte-Carlo Techniques for Automated Target Recognition," in *Sequential Monte Carlo Methods in Practice*, Chapter 26, Eds: N. de Freitas (Univ. of Cambridge), Arnaud Doucet (Univ. of Cambridge), and Neil Gordon (U.K. Defence Research Agency), Springer-Verlag, pp. 533-552, 2001.

6 Interactions/Transitions

6.1 Interactions with Government Organizations and Lockheed-Martin

- Aaron Lanterman presented a project review as part of the PCL Intelligence Conference at the Defense Intelligence Agency on August 7-8, 2001.

- Aaron Lanterman presented project reviews at three *DARPA ACMP Principal Investigators Meetings*: Strategic Analysis in Arlington, VA, April 4-6, 2001 and April 17-19, 2000, and in San Francisco, CA, June 30-July 1, 1999.

- On June 7-8, 2001, Shawn Herman, Rob Morrison, David Munson, and Aaron Lanterman attended and presented material at a two-day workshop on passive radar at the Air Force Institute of Technology (Dayton, OH) organized by AFIT Prof. Andy Terzouli. Other participants included Nick Willis (formerly of DARPA and Technology Service Corporation), Bob Ogrodnik (Air Force Research Lab, Rome), Dick Lodwig (Lockheed Martin Mission Systems), and Larkin Hastriter (U.S. Air Force). We helped advise six masters students on thesis topics relating to passive radar. The students were F-16 pilots on a NATO exchange program. Five were from Turkey; one was from Chile. In February 2001, Aaron Lanterman had a separate meeting with the AFIT group in Dayton to begin the collaboration.

- Beginning in September, 2000, Aaron Lanterman served on a Scientific Advisory Panel on Passive Coherent Location (PCL) systems. The panel, organized through The MITRE Co., was sponsored by Dr. Ron Pandolfi of the National Intelligence Council (NIC), and reported to Maj. Gen. John Landry (Ret.), the National Intelligence Officer for Conventional Military Issues. The final briefing to Gen. Landry took place on April 3-4, 2001, in McLean, VA. Other panel members included Nick Willis, Dick Lodwig, Scott Kordella (MITRE), David Barton (formerly with Raytheon), Al Bernard (Lincoln Labs), and John Sahr (Univ. of Washington). Panel members received a Certificate of Excellence Certificate of Excellence for "outstanding contributions to the National Intelligence Council and exceptional service to the Intelligence Community" for this work. In July, 2002, Aaron Lanterman will begin serving on a follow-up effort, also sponsored by NIC through MITRE, called the Air and Missile Defense Advisory Panel (AMDAP).

6.1.1 Meetings at Lockheed-Martin Mission Systems

The following meetings took place at Lockheed-Martin Mission Systems in Gaithersburg, MD:

- January 29, 1999: Six member of the UIUC group, Yoram Bresler, Pierre Moulin, David Munson, Shawn Herman, Aaron Lanterman, and Ana Martinez visited the PCL group at Lockheed-Martin Mission Systems. Lockheed Martin gave a demonstration of their Silent Sentry System.

- October 19, 1999: Lockheed Martin hosted the second project review for DARPA. Six members of the UIUC group, Richard Blahut, Yoram Bresler, Pierre Moulin, David Munson, Shawn Herman and Aaron Lanterman, were in attendance.

- April 12, 2001: Visit by Shawn Herman, Rob Morrison, David Munson, and Aaron Lanterman from the UIUC group.

6.1.2 Visits to UIUC by Lockheed Martin and DARPA Personnel

- May, 1998: Initial kickoff meeting with Dick Lodwig and Kevin Baugh (Lockheed Martin).

- November 11, 1998: Visit by Robert Taylor of Lockheed Martin Mission Systems.

- April 17, 1999: First site visit to UIUC by Dennis Healy (DARPA). Robert Taylor (Lockheed Martin) attended as well.

- March 9, 2000: Visit by Bert Bradford (Lockheed Martin).

- February 6, 2001: Visit by Bert Bradford (Lockheed Martin).

6.1.3 Internships

Shawn Herman joined Lockheed Martin Mission Systems for two six-week summer internships in 1999 (starting June 28) and 2000 (starting August 22). The first internship focused on scattering database generation using FISC. The second focused on two areas: 1) methods for compressing large scattering databases of aircraft, and 2) understanding bistatic low-frequency scattering of faceted targets.

6.2 Other Participation/Presentations at Meetings and Conferences

- Weng Chew presented a paper at the IEEE Antenna and Propagation International Symposium, July, 2000.

- Shawn Herman gave a presentation titled "A Particle Filtering Approach to Joint Radar Tracking and Automatic Target Recognition" at the First Annual ATR Theory Workshop at Wright State University, August 8-9, 2001.

- Yong Wu and Aaron Lanterman presented papers in the Algorithms for Synthetic Aperture Radar Imagery VIII conference at *SPIE AeroSense*, Orlando, FL, April 16-20, 2001.

- Aaron Lanterman assembled and chaired a session on "Information Theory and ATR" in the Automatic Target Recognition XI (April 16-20, 2001) and X (April 24-28, 2000) conferences at *SPIE AeroSense*, Orlando, FL. He also presented a paper on radio astronomy at the *URSI National Radio Science Meeting*, January 4-8, 2000, Boulder, CO.

- Yoram Bresler, Pierre Moulin, and David Munson, presented papers at the IEEE International Conference on Image Processing, Thesaloniki, Greece, Oct. 2001

- David Munson presented a paper at and the IEEE Radar Conference, Atlanta, GA, May 1-3, 2001.
- Shu Xiao presented a paper at the Asilomar Conf. on Signals, Systems, Systems, and Computers, Pacific Grove, CA, Oct. 31-Nov. 1.
- Yoram Bresler presented a paper at the IEEE Workshop on Variational and Level Set Methods of Computer Vision, Vancouver, CA, July 2001.
- Shawn Herman and Aaron Lanterman attended the *EMCC (Electromagnetic Code Consortium) Annual Meeting and HPC/MURI Project Reviews* at Boeing Phantom Works, St. Louis, MO, May 8-12, 2000.
- Yoram Bresler presented work on global confidence regions at the *IEEE International Conference on Acoustics, Speech, and Signal Processing*, Istanbul, Turkey 2000.
- Michael Brandfass (distorted Born methods), Pierre Moulin (performance bounds for ATR), Jong Ye (global confidence regions), Aaron Lanterman, and David Munson (two presentations, one on interferometric antenna spacings, the other a plenary talk on radar) gave presentations at *SPIE AeroSense*, April 24-28, 2000, Orlando, FL.
- David Munson attended the *IEEE International Conference on Image Processing*, October 24-27, 1999, Kobe, Japan; the *Integrated Imaging Workshop,* December 16, 1999, Army Research Office, Research Triangle, NC; the *IEEE Sensor Array and Multichannel Signal Processing Workshop*, March 16-17, 2000, Cambridge, MA; and the *IEEE International Conference on Acoustics, Speech, and Signal Processing*, June 5-9, 2000, Istanbul, Turkey.
- Weng Chew attended the *AFOSR Electromagnetics Workshop*, January 6-9, 1999, San Antonio, TX; presented a paper at the *PIERS Conference*, March 20-27, 1999, Taipei, Taiwan; attended the *TBM Signatures Conference*, May 26-28, 1999, Huntsville, AL; visited NSF, AFOSR, and DARPA in Washington, DC during June 22-25, 1999; gave a presentation at the *30th AIAA Plasmadynamics and Laser Conference*, June 28-July 1, 1999, Norfolk, VA; and presented a paper at the *IEEE AP-S/URSI International Symposium*, July 10-15, 1999, Orlando, FL.
- Pierre Moulin co-chaired the *IEEE Workshop on Detection, Estimation, Classification, and Imaging*, February 24-26, 1999, Sante Fe, NM; co-organized the *IEEE International Conference on Image Processing*, October 4-7, 1998, Chicago, IL; and presented a paper at the *Conference on Information Sciences and Systems*, March 1999, Baltimore, MD.
- David Munson attended the *IEEE International Conference on Image Processing*, October 4-7, 1998, Chicago, IL; the *IEEE International Conference on Acoustics, Speech, and Signal Processing*, March 14-18, 1999, Phoenix, AZ; the *IEEE Radar Conference*, April 20-22, 1999, Waltham, MA; and the *DSPSCA Workshop*, July 7-9, University of Virginia, Charlottesville, VA.

- Aaron Lanterman presented two papers at *SPIE AeroSense*, April 5-9, 1999, Orlando, FL and presented a poster at the *IEEE Workshop on Detection, Estimation, Classification, and Imaging*, February 24-26, 1999, Sante Fe, NM.

- Aaron Lanterman and Sviatoslav Voloshynovskiy attended the *IEEE International Conference on Image Processing*, October 4-7, 1998, Chicago, IL.

- Shawn Herman and Jong Ye attended the *IEEE Workshop on Detection, Estimation, Classification, and Imaging*, February 24-26, 1999, Sante Fe, NM.

6.3 Visitors

- Upon the advice of Arje Nachman of AFOSR, **David Colton** (Mathematical Sciences, Univ. of Delaware) visited UIUC to present work on "linear sampling" methods of nonlinear inverse scattering and discuss potential areas of collaboration on January 24, 2000. This meeting resulted in work on a paper co-authored by Michael Brandfass, Aaron Lanterman, and Karl Warnick which has appeared in Inverse Problems.

- **Hao Ling** (Univ. of Texas at Austin) presented work on scattering center representations for radar signatures on February 4, 1999.

- **Lee Potter** (Ohio State University) presented work on scattering center representations and ultrawideband radar on March 23, 1999.

- **Joseph A. O'Sullivan** (Washington Univ. in St. Louis) visited to discuss work on exploiting statistical models for radar data in formulating ATR algorithms for the DARPA MSTAR data set on June 4, 1999.

7 New Discoveries, Inventions, or Patent Disclosures

Shu Xiao, Yoram Bresler, and David C. Munson, Jr., "Fast Native Divergent-Beam Reconstruction Algorithms for Tomography," Invention Disclosure, Feb. 26, 2002, University of Illinois, Urbana, IL. Patent application under preparation.

8 Honors/Awards

- **Yoram Bresler** was named an IEEE Fellow in January 1999 "for contributions to computer based imaging and sensor array processing." He is the recipient of two Senior (Best Paper) awards of the IEEE Acoustics, Speech, and Signal Processing Society in 1988 and 1989, and was a coauthor of a paper awarded a Best Young Author award by the same society in 2002. He received a 1991 Presidential Young Investigator Award of the National Science Foundation, a 1995-6 Technion (Israel) Fellowship, and a 1998 Xerox Senior Award for Faculty Research. In 1999 he was named a University of Illinois Scholar, and was appointed an Associate at the University of Illinois Center for Advanced Study in 2001-2.

- **Richard E. Blahut** was named a Fellow of the IBM Corporation in 1980, a member of the National Academy of Engineering in 1990, and an IEEE Fellow in 1991. He received the IEEE Alexander Graham Bell Medal in 1998. In 2001, he became Head of the Department of Electrical and Computer Engineering at the Univ. of Illinois.

- **Weng C. Chew** was named an IEEE Fellow in 1993 and has received the IEEE Graduate Teaching Award. He received Founder Professorship from the College of Engineering of the Univ. of Illinois. He received the UIUC Campus Wide Professional and Graduate Teaching Award in 2001 and the S.A. Schelkunoff Best Paper Award (coauthored with J.S. Zhao) for a paper published in the IEEE Transactions on Antennas and Propagation in 2001. Recently, he has been elected by ISA Citations to the category of Most Highly Cited Authors (belonging to the top 0.5 percent).

- **Aaron D. Lanterman** joined the faculty of the School of Electrical and Computer Engineering at the Georgia Institute of Technology as an Assistant Professor in August, 2001. In September 2001, he received the Certificate of Excellence from the National Intelligence Council for "outstanding contributions to the National Intelligence Council and exceptional service to the Intelligence Community" for consulting work related to passive radar systems.

- **David C. Munson, Jr.** was named an IEEE Fellow in 1991 and was the Founding Editor-in-Chief of the IEEE Transactions on Imaging Processing. In 1998 he received the newly established Outstanding Teaching Award for Faculty in the Department of Electrical and Computer Engineering at the University of Illinois. In Fall 1999 he was the Texas Instruments Visiting Professor at Rice University. In 2000-2001, he was a Distinguished Lecturer of the IEEE Signal Processing Society, and in 2001 he was named the Robert C. MacClinchie Distinguished Professor of Electrical and Computer Engineering at the University of Illinois.

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9 Appendix

This appendix contains the following selected papers. Full references are available in the Publications section. The titles are given here to facilitate rapid location of specific papers, and ensure that the report is complete.

- "A Particle Filtering Approach to FM-Band Passive Radar Tracking and Automatic Target Recognition"
- "Deconvolution Techniques for Passive Radar Imaging"
- "Wide-Angle Radar Imaging using Wigner-Ville Distributions"
- "An Experimental Study of a New Entropy-Based SAR Autofocus Technique"
- "Efficient Implementation of an Expectation-Maximization Algorithm for Imaging Diffuse Radar Targets"
- "A Comparison of the Colton-Kirsch Inverse Scattering Methods with Linearized Tomographic Inverse Scattering"
- "A Multilevel Fast Multipole Based Approach for Efficient Reconstruction of Perfectly Conducting Scatterers"
- "Asymptotic Global Confidence Regions in Parametric Shape Estimation Problems"
- "Cramér-Rao Bounds for 2-D Target Shape Estimation in Nonlinear Inverse Scattering Problems with Application to Passive Radar"
- "Cramér-Rao Bounds for Parametric Shape Estimation in Inverse Problems"
- "Global Confidence Regions for Parametric Surface Estimation"
- "A Self-Referencing Level-Set Method for Image Reconstruction from Sparse Fourier Samples"
- "Complexity Regularized Shape Estimation from Noisy Fourier Data"
- "An $N^2 \log N$ Back-Projection Algorithm for SAR Image Formation"
- "A Fast Back-Projection Algorithm for Bistatic SAR Imaging"
- "Fast Fourier Transform of Sparse Spatial Data to Sparse Fourier Data"
- "A Sparse Data Fast Fourier Transform (SDFFT) - Algorithm and Implementation"
- "Optimal Antenna Spacings in Inferferometric SAR"